signal decreased from -53 dBm to -68 dBm). Nonetheless, this extrapolation to lower signal levels constitutes an additional potential source of error in these plots that was not present in the Figures 10-4 to 10-10.

Comparing the modeled curve for receiver M1 in Figure 10-15 to the measurements for that receiver at $D = D_{MIN} + 3$ dB in Figure 10-2, we see that the modeled threshold along the equal-power line is about -32 dBm, whereas the measured threshold is about -30 dBm. This 2 dB error can be attributed to the anomalous behavior of the receiver for D = -68 dBm in the vicinity of the equal power line (Figure 10-2). In fact, if the model had been computed from the IP3 / $SNR_R^{1/2}$ value for D = -53 dBm, it would match the measurement within 0.3 dB.

Table 10-2 summarizes the information in the model plots. Note that the statistics provided here apply to the subset of combinations of channel offsets and TVs for which a measurement of IP3 / $SNR_R^{1/2}$ was obtained and for which AGC was judged to be inactive at -68 dBm (for tuner stages prior to the nonlinearity that causes the observed IM3) so that IP3 could be assumed constant below that level. In most cases, the greatest susceptibility to interference is predicted to occur on channel N+2K, where the susceptibility may increase by amounts ranging from 6 to 59 dB when a large signal is present on N+K.

*Table 10-2. Range of Impact of IM3 from Pairs of Undesired Signals When $D = D_{MIN} + 3$ dB*

| | Statistics of Undesired Signal Levels (dBm) | | | | |
|---|---|---|---|---|---|
| | Min. | Median | Mean | Max. | Standard Deviation |
| **Susceptibility increase on N+K due to N+2K:** | | | | | |
| Susceptibility to N+K begins increasing at $U_{N+2K}$= | -68.7 | -39.5 | -41.3 | -12.4 | 14.4 |
| Susceptibility to N+K reaches max. at $U_{N+2K}$= | -32.3 | -9.0 | -11.1 | -2.9 | 6.7 |
| $U_{N+K}$ threshold before increase in susceptibility | -38.5 | -23.9 | -23.7 | -12.3 | 6.4 |
| $U_{N+K}$ threshold after increase in susceptibility | -50.0 | -39.4 | -38.9 | -30.7 | 5.2 |
| Net increase in susceptibility caused by $U_{N+2K}$ | 3.2 | 15.4 | 15.1 | 29.6 | 7.2 |
| **Susceptibility increase on N+2K due to N+K:** | | | | | |
| Susceptibility to N+2K begins increasing at $U_{N+K}$= | -50.0 | -39.4 | -38.9 | -30.7 | 5.2 |
| Susceptibility to N+2K reaches max. at $U_{N+K}$= | -38.5 | -23.9 | -23.7 | -12.3 | 6.4 |
| $U_{N+2K}$ threshold before increase in susceptibility | -32.3 | -9.0 | -11.1 | -2.9 | 6.7 |
| $U_{N+2K}$ threshold after increase in susceptibility | -68.7 | -39.5 | -41.3 | -12.4 | 14.4 |
| Net increase in susceptibility caused by $U_{N+K}$ | 6.4 | 30.8 | 30.2 | 59.3 | 14.3 |

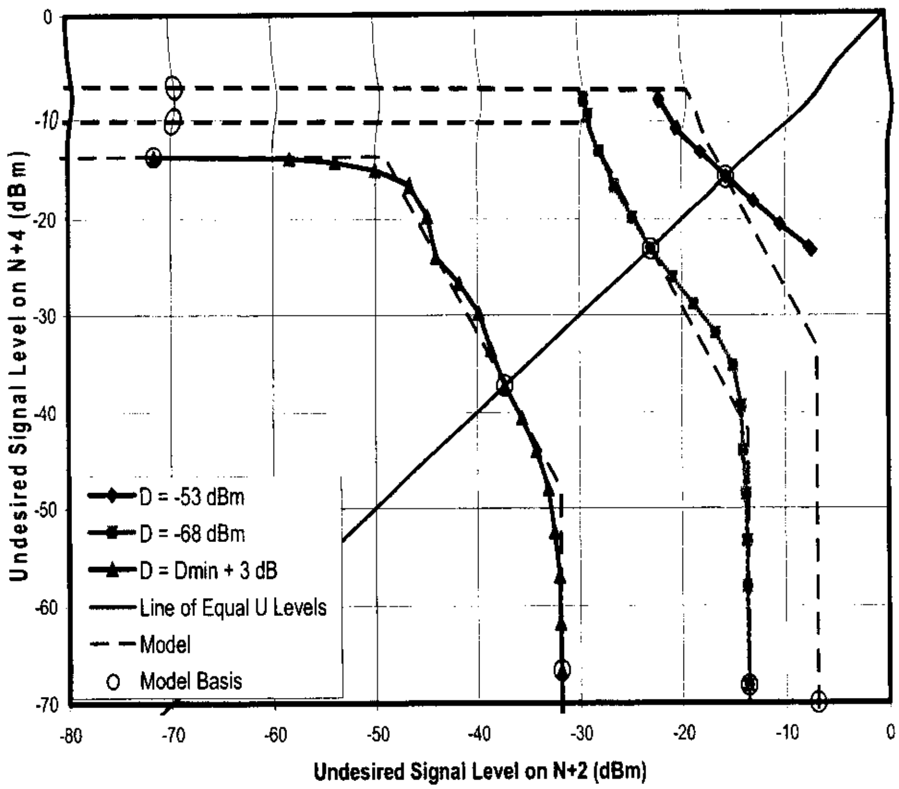


*Figure 10-1. Threshold U for Paired, Unequal Undesired Signals on Receiver G4*

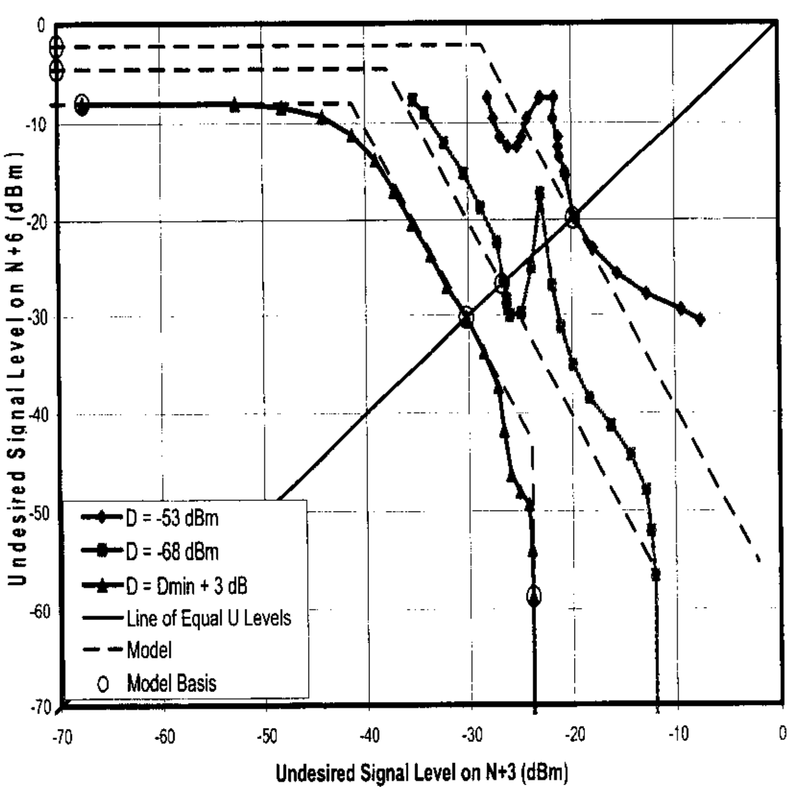


*Figure 10-2. Threshold U for Paired, Unequal Undesired Signals on Receiver M1*

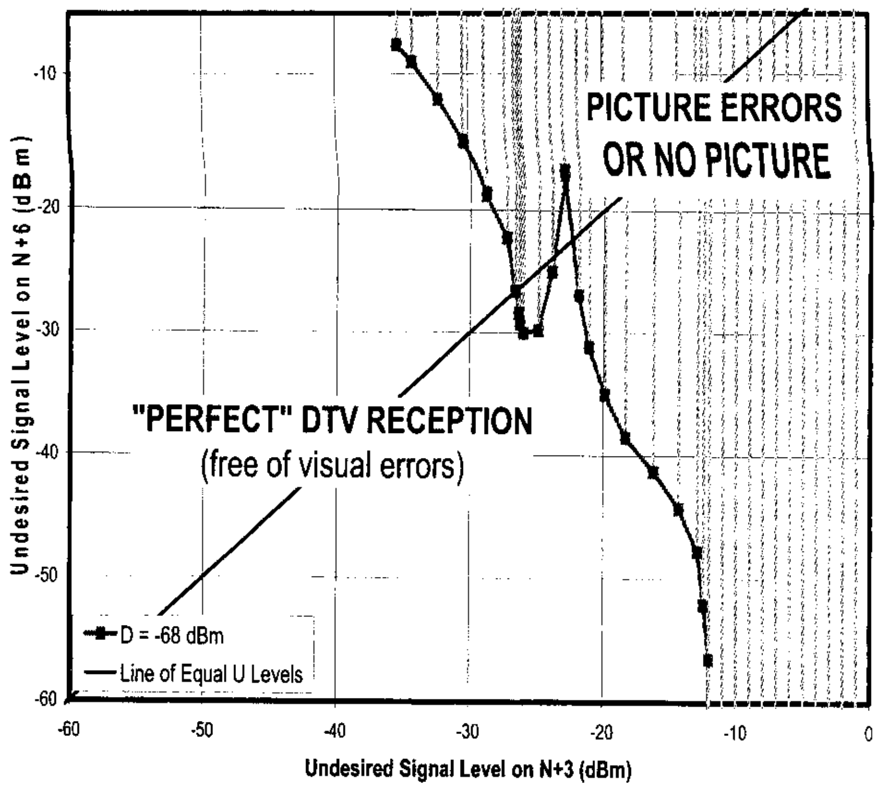


*Figure 10-3. Threshold U for Paired, Unequal Undesired Signals on Receiver M1 at D = -68 dBm*

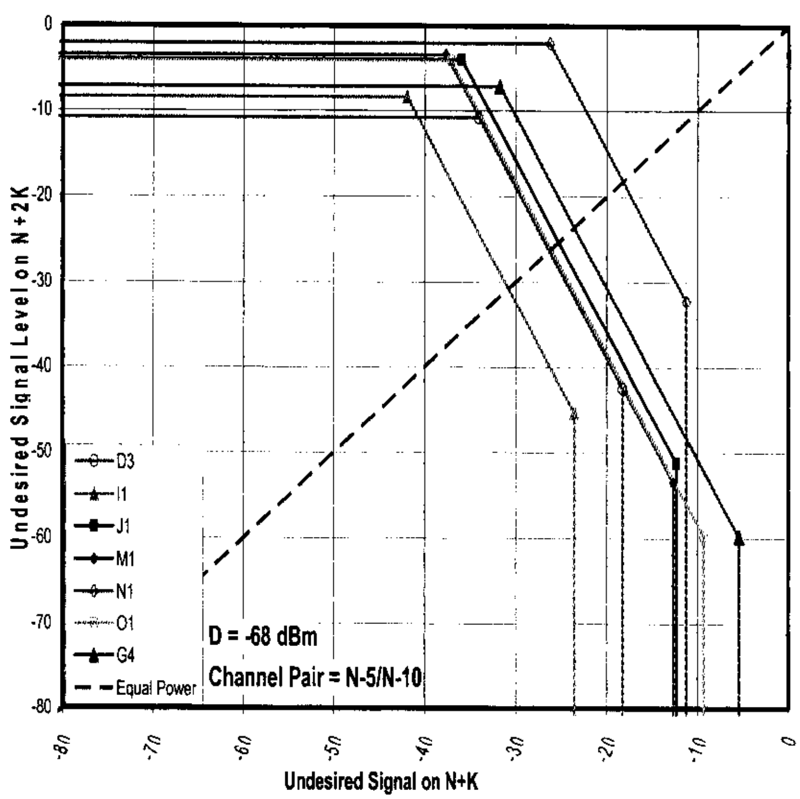


*Figure 10-4. Modeled Thresholds for N-5/N-10 with D = -68 dBm*

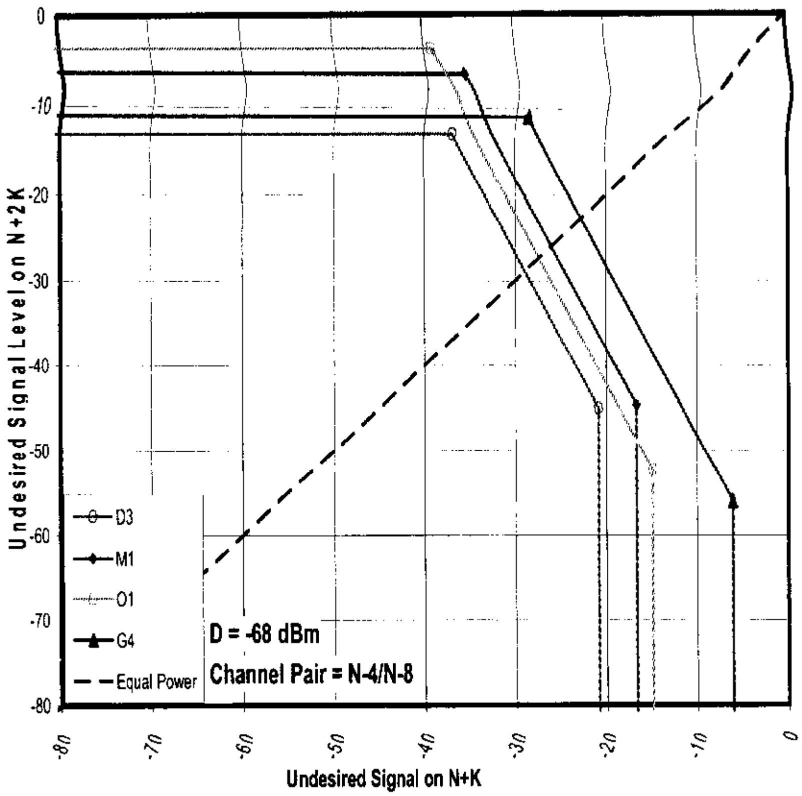


*Figure 10-5. Modeled Thresholds for N-4/N-8 with D = -68 dBm*

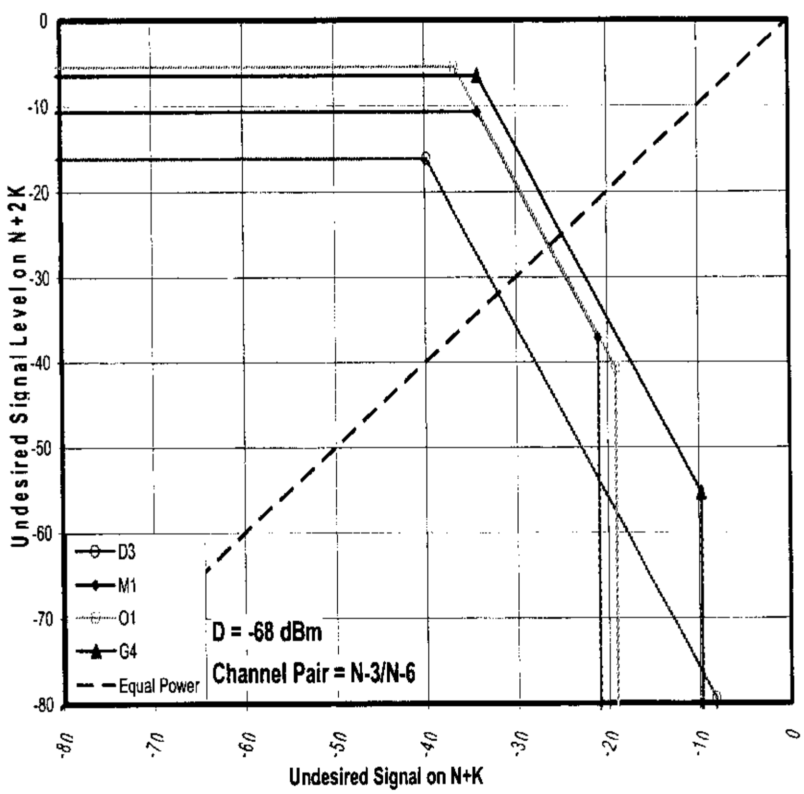


*Figure 10-6. Modeled Thresholds for N-3/N-6 with D = -68 dBm*

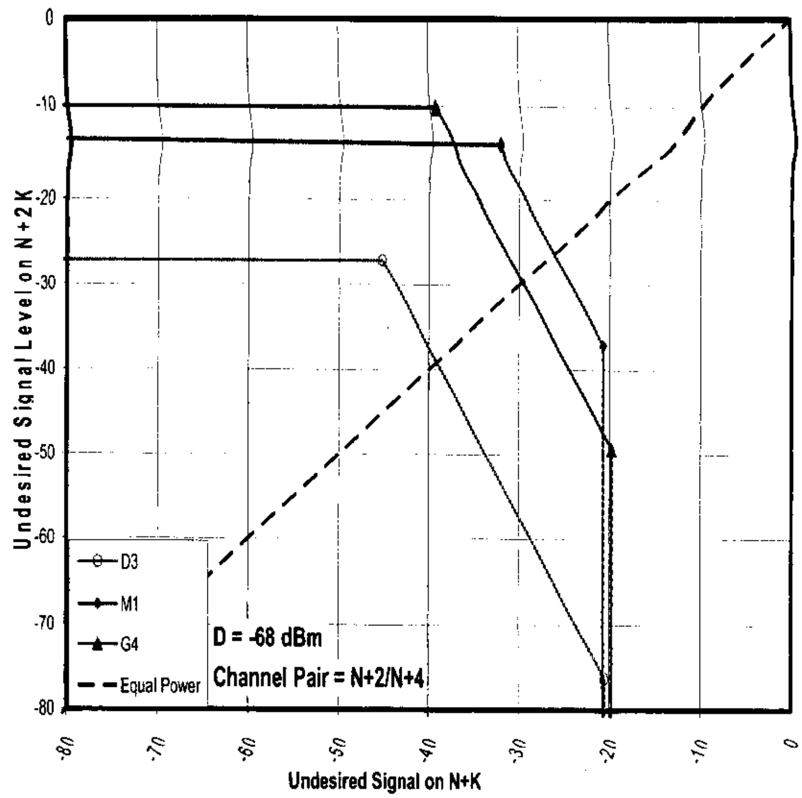


*Figure 10-7. Modeled Thresholds for N+2/N+4 with D = -68 dBm*

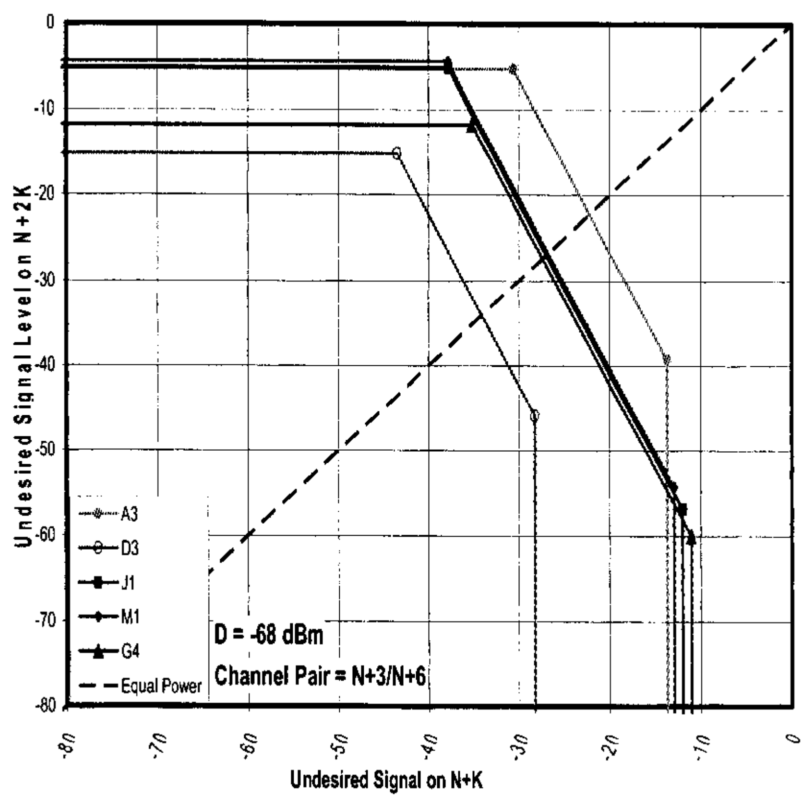


*Figure 10-8. Modeled Thresholds for N+3/N+6 with D = -68 dBm*

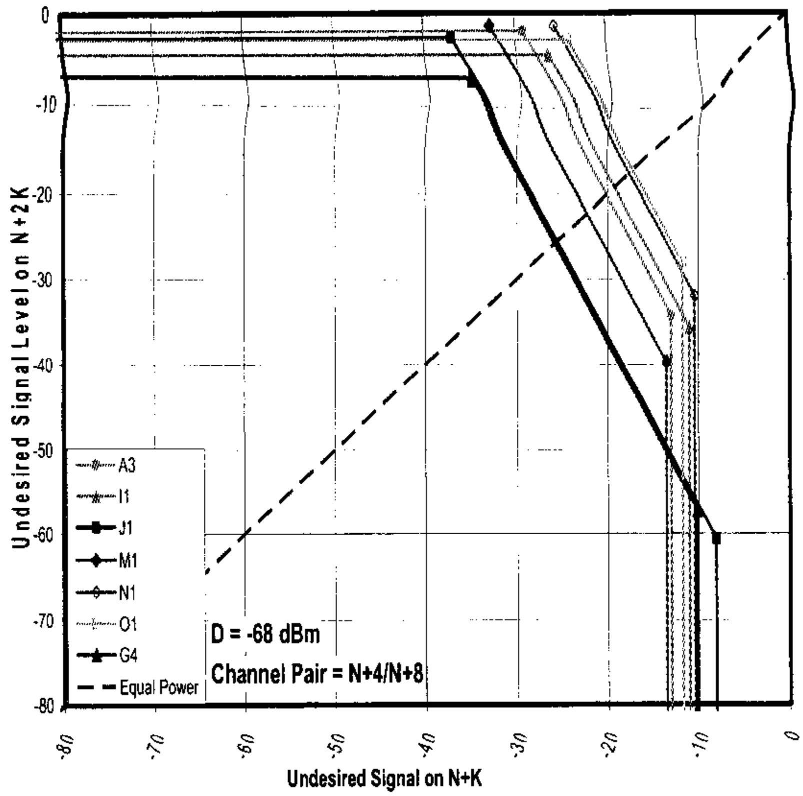


*Figure 10-9. Modeled Thresholds for N+4/N+8 with D = -68 dBm*

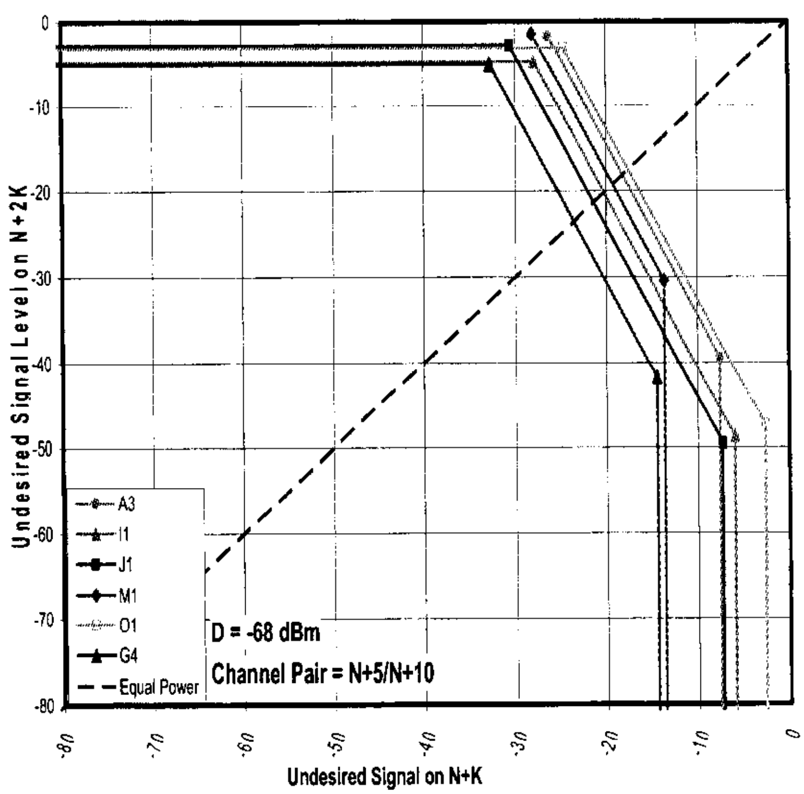


*Figure 10-10. Modeled Thresholds for N+5/N+10 with D = -68 dBm*

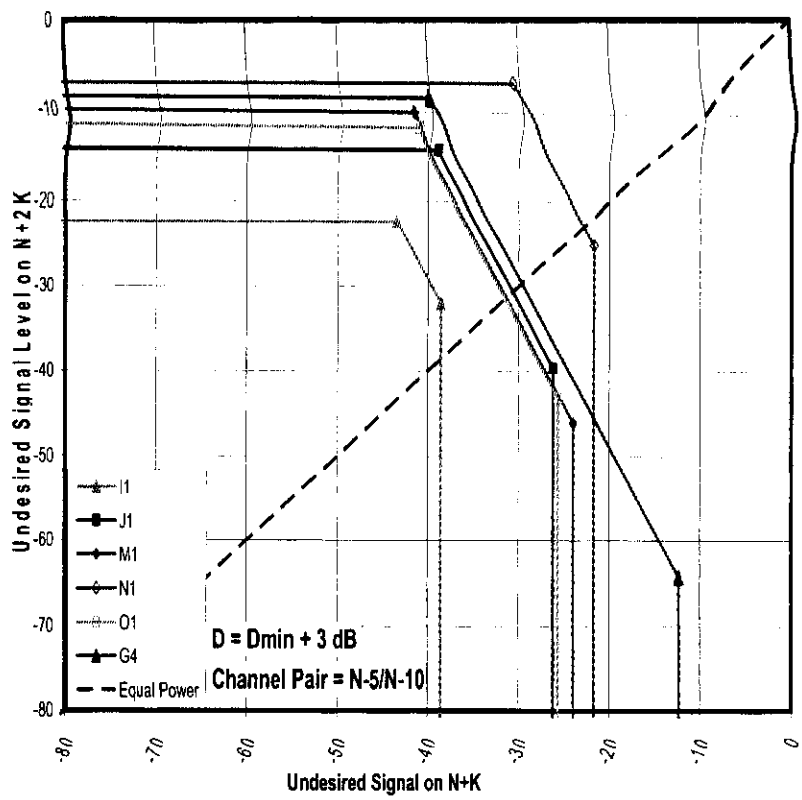


*Figure 10-11. Modeled Thresholds for N-5/N-10 with D = $D_{MIN}$ + 3 dB*

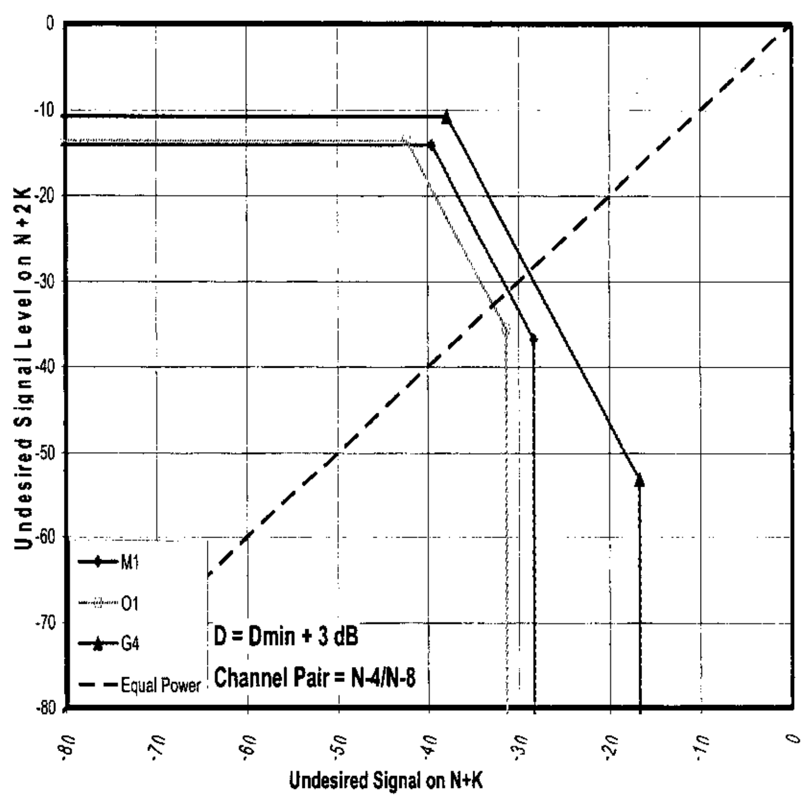


*Figure 10-12. Modeled Thresholds for N-4/N-8 with D = $D_{MIN}$ + 3 dB*

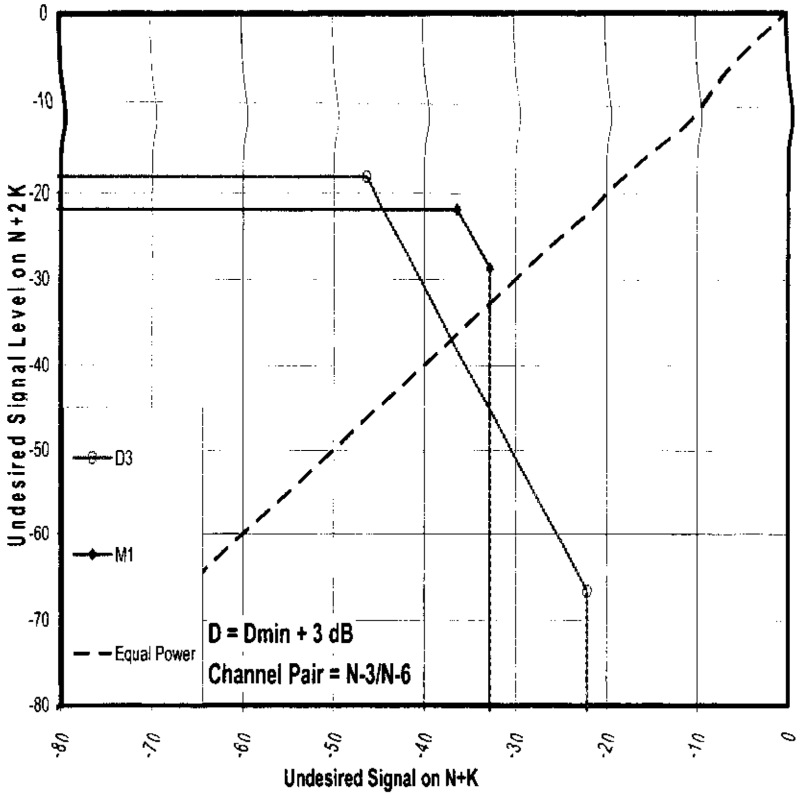


*Figure 10-13. Modeled Thresholds for N-3/N-6 with $D = D_{MIN} + 3$ dB*

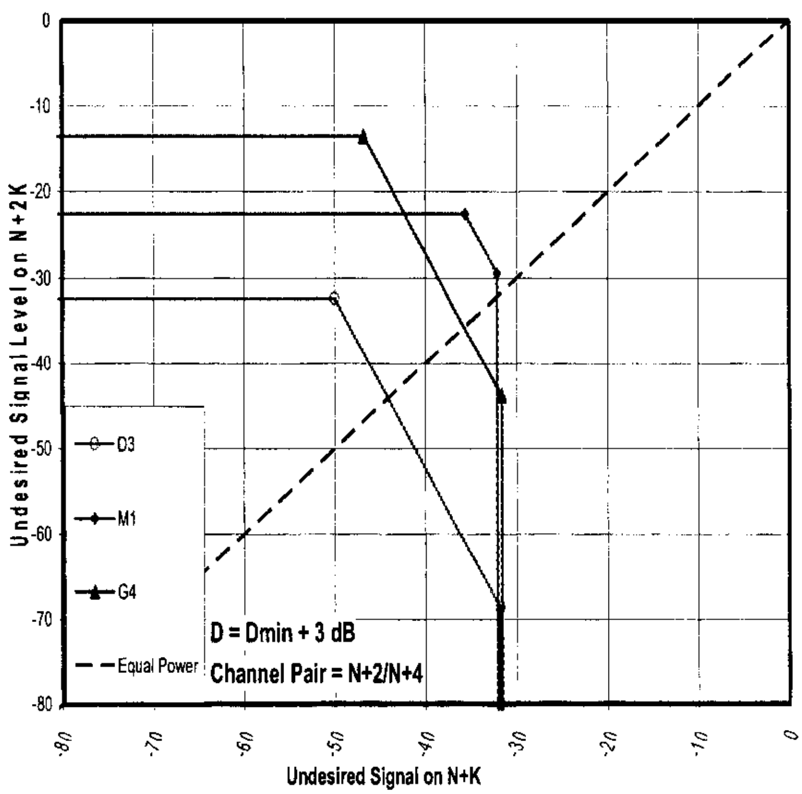


*Figure 10-14. Modeled Thresholds for N+2/N+4 with $D = D_{MIN} + 3$ dB*

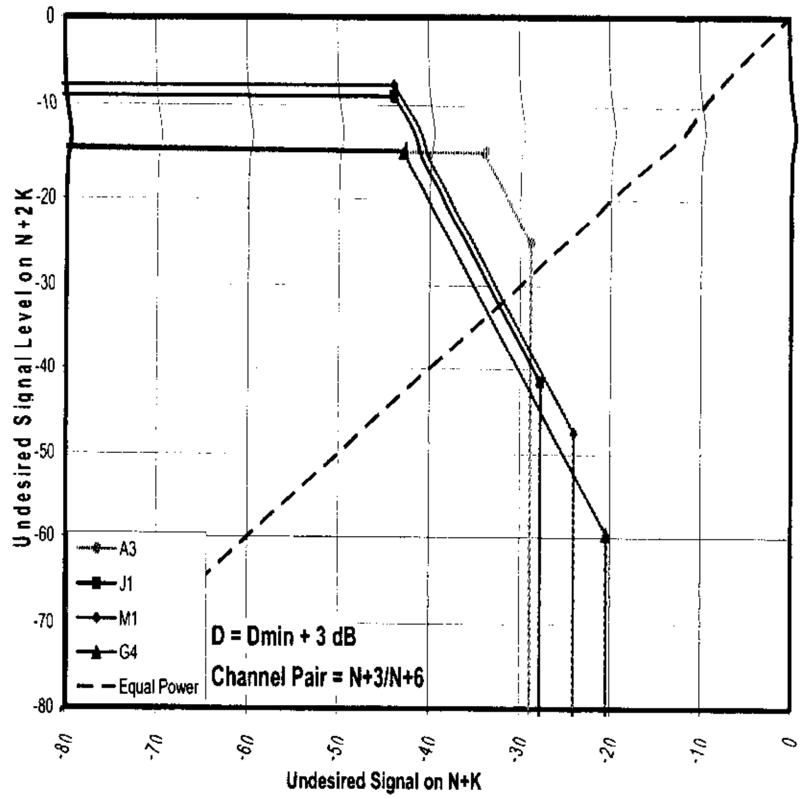


*Figure 10-15. Modeled Thresholds for N+3/N+6 with D = $D_{MIN}$ + 3 dB*

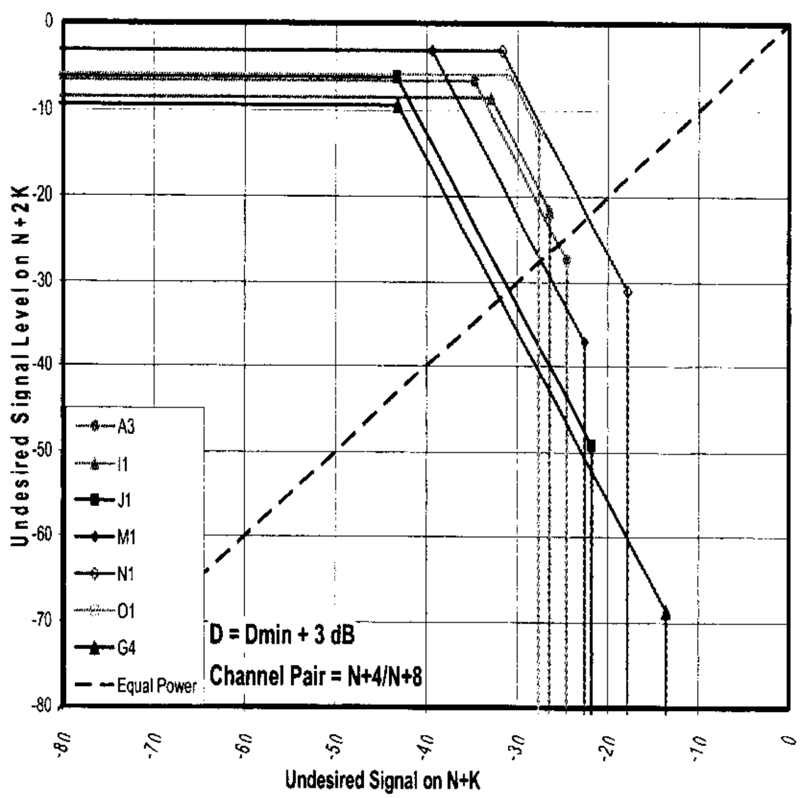


*Figure 10-16. Modeled Thresholds for N+4/N+8 with D = $D_{MIN}$ + 3 dB*

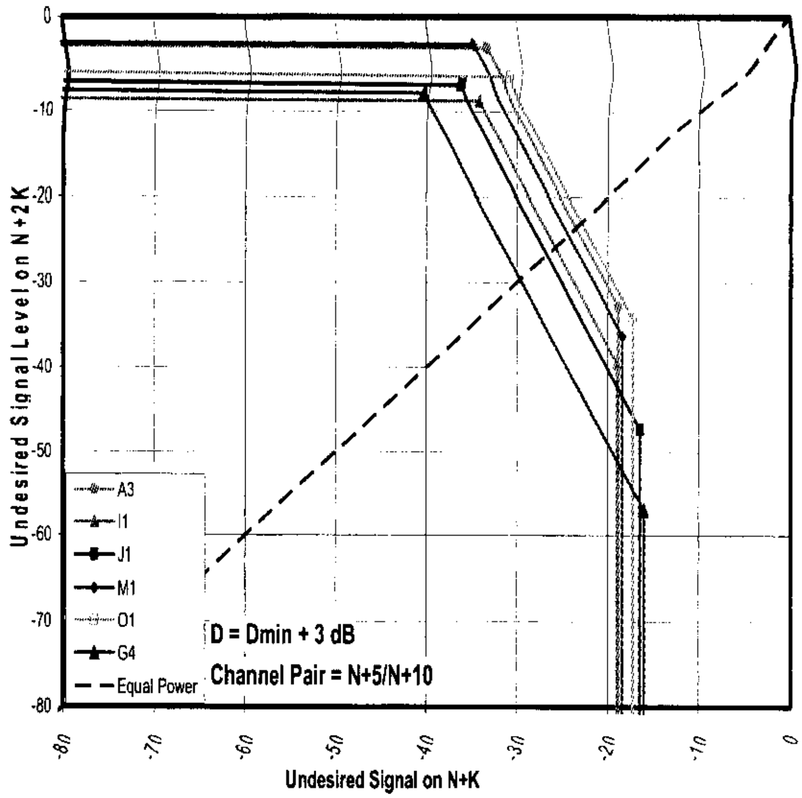


*Figure 10-17. Modeled Thresholds for N+5/N+10 with D = $D_{MIN}$ + 3 dB*

# CHAPTER 11
# SINGLE AND PAIRED REJECTION RATIOS VERSUS DESIRED SIGNAL LEVEL—A DETAILED EXAMPLE

This chapter presents measurements of D/U ratio and of U at threshold as functions of desired signal level D based on a detailed set of measurements for one DTV receiver, D3. The tests included single interferers as well as paired interferers spaced to place IM3 products in the desired signal channel. The amount of effort involved in making these measurements precluded such an evaluation of other receivers; however, the results from this one set of measurements provide some insight into the behavior of interference susceptibilities that will aid in developing an understanding of test results for other DTV receivers.

Figure 11-1 shows measurements of D/U versus D for receiver D3—measured for the desired channel N = 51. Chronologically, this was the first rejection performance work done under this test program apart from a crude set of measurements used to select the TV for this test. The test was performed to provide some insight into the variation of certain interference effects with desired signal level prior to testing at fixed desired signal levels.*

The *dashed* curves on the plot represent measurements using pairs of equal-level undesired signals at N+1/N+2, N+2/N+4, N+3/N+6, and N+4/N+8. The solid lines represent measurements with single undesired signals on channels N+1 through N+7, N+14, and N+15. Curves labeled "N+1 (No Filter)" and "N+1/N+2 (No Filter)" are measurements performed with the filter removed from the test setup; this allowed the test setup to create higher interfering signal levels.†

Though the number of curves on each plot makes it difficult to identify individual results, the curves are all combined on one graph to illustrate both the diversity and the commonality in the behavior of the various interference phenomena. The data will be dissected into separate charts later in the chapter.

The first point on each curve is a measurement with the desired signal at approximately 1 dB above the minimum signal $D_{MIN}$ for the TV. ($D_{MIN}$ is the desired signal level corresponding to the threshold of visibility (TOV) of picture degradation in the absence of interference.) The second point is 3 dB above $D_{MIN}$. The third point is at $D_{MIN}$ + 5 dB, and all subsequent points are at 5-dB intervals.

Note the following reference levels on the graph.

- Diamonds (◆) on the X-axis mark the following desired signal levels.

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* Our expectation at the onset of this project was that the primary vulnerabilities that would need to be investigated would be the first-adjacent channel response, the mixer image response, and possibly the effects of third-order intermodulation (IM3) distortion for signal pairs. In order to gain an understanding of the nature of these interference vulnerabilities, we decided to conduct detailed measurements on a TV receiver that exhibited high enough interference susceptibilities for those cases to permit measurement over a wide range of signal levels. Prior to procurement of custom filters for this project, measurements on first-adjacent channels were not feasible with the signal generators available at the FCC Laboratory; however, crude measurements could be made at other channel spacings. Such measurements were performed on eight TVs (including three that were used in tests reported in this document) with the goal of identifying a TV that exhibited relatively high mixer image and third-order intermodulation (IM3) effects. The mixer image measurements were performed using a single undesired signal at N+15 and a desired signal level of -68 dBm; IM3 measurements were performed for undesired signal pairs at N+1/N+2 and at N+2/N+4 with each undesired signal set for -14 dBm. (It was thought, incorrectly, that such high signal levels might be necessary to enable observation of IM3 effects.) The selected receiver (D3) had the highest IM3 effects and the second highest mixer image response among the three tested receivers at these levels.

† Removal of the filter was possible because the high D/U ratios (above -20 dB) for those few measurements reduced the otherwise stringent requirement on splatter of the undesired signal into the desired channel.

◊ -84 dBm is the received level of a DTV signal at the edge of coverage of a broadcast station (per OET-69); this is also marked by a black vertical dashed line.
◊ -68 dBm, -53 dBm, and -28 dBm are the desired signal levels that the ATSC designated as "weak", "moderate", and "strong", respectively; most D/U measurements shown elsewhere in this report were made at these three levels.
◊ Not shown (off scale to the right) is -8 dBm, the largest expected DTV signal.

- A diagonal dashed line corresponds to an undesired signal level of -8 dBm—equal to the maximum DTV signal that is expected at the input to a TV receiver.

Figure 11-2 shows the same measurement data as Figure 11-1, but it is presented as undesired signal level at threshold rather than as D/U ratios. Thus, in Figure 11-2, high points on the graph represent high rejection performance rather than high susceptibility to interference.

Figures 11-3 and 11-4 are plots of slope of log-D versus log-U and of log-U versus log-D, respectively. The slope information will aid in evaluating order of the interference mechanisms represented by the curves. The slope of log-D versus log-U directly indicates order of the interference mechanism (except where AGC affects the results and at desired signal levels near $D_{MIN}$); thus, an interference mechanism that is third-order in terms of the undesired signal level should have a slope of 3 in Figure 11-3. Figure 11-4 is included because the interference effect of certain interference mechanisms such as cross-modulation is directly proportional to desired signal as well as being dependent on the undesired signal level; the result is predicted to be an infinite slope in Figure 11-3 or a zero slope in Figure 11-4. Slopes were computed from adjacent pairs of measurement points from Figures 11-1 and 11-2 and are plotted at the midpoint of the pair. Thus, for example, the slope that was computed based on measurements at desired signal levels of -68 dBm and -63-dBm was plotted at -65.5 dBm.

## GENERAL OBSERVATIONS

Returning to Figure 11-1, we make some general observations regarding the interference rejection results.

First, in examining the left portion of the graph—for desired signals less than about -60 dBm—we note the following.

- Some of the curves are—for the most part—horizontal lines, indicating constant D/U ratio as desired signal is varied. This result is true for interference at N+14 and N+15 because interference effects on these channels result from the receiver's mixer image—a linear interference mechanism. Less expected is that the curves for N+1 and N+2 are flat, a topic that will be discussed later. Totally unexpected is the fact that interference from a pair of undesired signals at N+1/N+2 also exhibits a flat D/U and that the D/U is nearly identical to that for N+1 alone, over part of the curve. N+1/N+2 is expected to generate IM3—a third order nonlinear process (third order when the amplitudes of both undesired signals are adjusted together).
- Some of the curves exhibit upward slopes of log(D/U) versus log-D. Many of the slopes appear to be identical, but others—such as those for N+3 and for N+7—are steeper.
- While most of the curves appear to be nearly straight lines, all bend upward at their left-hand ends, where the desired signal level approaches $D_{MIN}$.

Next, looking at the middle to right hand portions of the graph, we note the following.

- Most of the curves that are upward-sloped on the left exhibit an abrupt bend—becoming approximately horizontal. The D/U's, which were increasing as straight lines (on the dB versus dB scale),* dip down gradually after the bend, but then eventually begin to increase again. The bend is believed to be associated with AGC action in the receiver for reasons discussed in Chapter 8.

* Note that linear appearance on a log-log plot (such as these plots in decibels) does not necessarily indicate a linear function but rather a fixed-order function such as $X^M$ where M is a fixed exponent. The slope of the plot of D versus

- The abrupt bend in most of the curves occurs at the same desired signal level of approximately -53 dBm. We believe that the receiver AGC begins reducing RF gain at this desired signal level.
- One curve, that for interference at N+2/N+4, exhibits its bend at a lower desired signal level—approximately -58 dBm. In this case, it is considered likely that AGC action is initiated—not based on the desired signal level alone, but rather based on the total power reaching an AGC sensing point in the receiver. In this case, the approximately -37 dBm undesired power on channel N+2 (see Figure 11-2) is sufficient that—after filtering within the tuner—it combines with the desired signal power to engage the AGC.
- The curves for N+1 and for the N+1/N+2 pair gradually shift from their horizontal slope on the left of the graph to upward slopes on the right half of the plot. The flat portions at the left side of both curves is believed to be due to AGC action similar to that discussed in the previous bullet; in this case, AGC action based on the level of the undesired signal at N+1 exceeding a threshold on the order of -40 dB or lower results in the curves being flat in the left hand region. In the upward-sloped region, the D/U of the N+1/N+2 curve tracks that of the N+1 curve, but at a D/U ratio that is about 3-dB higher than that for N+1. This portion of both of the curves is likely to be the result of IM3 occurring either at an early RF amplifier stage that is not controlled by the AGC, or at the same point as the other IM3 examples (probably the mixer), but after the AGC's gain reduction capability for those stages has reached its limit.

## *IM3 WITH PAIRED UNDESIRED SIGNALS*

We start by assessing the paired-signal results, because those results enable us to understand the N+1 results. To provide a simpler view, Figure 11-5 was created to show D/U for the four tested pairs (the dashed lines) and for the single interferers associated with them (solid lines). All other data has been removed from the plot.

### N+2/N+4, N+3/N+6, and N+4/N+8

We first examine the paired signal test results that did not involve the first adjacent channel. We note that the D/U curves for N+2/N+4, N+3/N+6, and N+4/N+8 (Figure 11-5) have two distinctive regions: an up-sloped region on the left and more horizontal, but dish-shaped region to the right. The dish-shaped region slopes downward initially, but then begins to trend upward (on two of the three curves) on the far right. The two regions are separated by an abrupt bend in each curve, occurring at a desired signal level of either -53 dBm or -58 dBm.

Looking at the sloped portions of the curves to the left of D = -58 dBm, we see that the D/U ratios (and thus the interference effects) of the paired signals (dashed curves) are higher than those of the corresponding single signals.* For example, the D/U ratios for N+2/N+4 (the top curve) are significantly higher than those for N+2 and N+4 individually. This implies that the pair of undesired signals combines synergistically so as to create an interference effect larger than the sum of the interference effects of the individual signals. This synergism is the result of third-order intermodulation (IM3) distortion occurring somewhere in the DTV receiver—most likely in the mixer.

Looking at the slope of log-D versus log-U (Figure 11-3), we see that the slope measurements of the paired signal curves in this region fall between 3 and 4 dB/dB. The expected slope for an IM3 process with both undesired signals varied in amplitude together is 3 dB/dB. We take this as further confirmation of IM3 as the primary cause of the paired signal interference.

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U on a log-log scale provides the value of the exponent that describes the *order* of the interference mechanism. A linear process (M=1) will have a slope of one on a log-log plot.

* Measurements of D/U for N+8 were not performed in this test; however, measurements presented in Chapter 6 show that D/U for N+8 is quite small.

While we had expected the paired-signal IM3 to be significant only at high signal levels, it is interesting to note in Figure 11-1 that IM3 for the N+2/N+4 pair causes higher interference susceptibility than any single-channel interferer—*including the first-adjacent channel—all the way down to a desired signal level* only 1 dB above the lowest signal level at which the receiver can operate ($D_{MIN}$). Similarly, susceptibility to interference from an undesired signal pair at N+3/N+6 is greater—even at signal levels down to $D_{MIN}$ + 1 dB—than from any single channel except the first adjacent channel, and it exceeds even that except when the desired signal drops to $D_{MIN}$ + 3 dB or below. Even on N+4/N+8, interference susceptibility exceeds that of any single channel, except the first adjacent one, down to 2 dB above $D_{MIN}$; mixer image interference at N+15 barely surpasses N+4/N+8 interference effects only at $D_{MIN}$ + 1 dB.

We also note in Figure 11-5 that D/U ratios of the N+K/N+2K pairs fall gradually as K increases. The fact that IM3 is observed even for N+4/N+8 suggests that it occurs at a place in tuner at which undesired signals all the way out to N+8 (for the N+4/N+8 pair) are still present. The gradual fall with increasing K suggests that the nonlinearity causing these IM3 effects is after the tracking filter in the RF section. We surmise that the IM3 effects observed on this part of each of the three paired-signal curves being discussed in this section is caused by nonlinearity at the mixer.

We now note the abrupt bend in each of the three curves (for N+2/N+4, N+3/N+6, and N+4/N+8), representing a change in character of the interference effect. Based on discussions in the Chapter 8, we attribute that bend and subsequent leveling of the D/U plots to AGC action in the tuner. Specifically, we conclude that, beginning at this bend, the AGC adjusts gain downward with further increases in signal level and that this gain adjustment occurs in the RF amplifier stage since the nonlinearity that is affected is probably at the mixer.

We further note that the curves for N+3/N+6 and N+4/N+8 exhibit this AGC bend at identical levels of desired signal, D = -53 dBm. Four of the single-interferer curves in Figure 11-1 exhibit this same bend point. We conclude that the RF AGC engages whenever the desired signal exceeds -53 dBm.

### *N+2/N+4—A Different AGC Point*

On the other hand, the N+2/N+4 curve exhibits its AGC bend when D = -58 dBm. This suggests an AGC action that is influenced by the *undesired* signal level. The bend occurs when the undesired signal level applied to both N+2 and N+4 reaches -36.5 dBm (Figure 11-2). The desired-signal-driven AGC thresholds for the other curves occur when undesired signals on channel N+3 or beyond are at signal levels ranging from -31 to -17 dBm (Figure 11-2); these levels apparently do not result in AGC action since all bends occurred at the same *desired* signal level. In particular, the bend in the N+4 curve at D = -53 dBm and U = -25 dBm suggests that the early bend in the N+2/N+4 curve is entirely due to N+2 as opposed to N+4.

Hence, it is clear that the RF gain reduction in at least this one case—and maybe in all—is triggered by total signal level (desired plus undesired) at a point in the tuner where total power from each channel is influenced by filtering. Assuming both AGC mechanisms are the same, the fact that AGC action begins at a desired signal level of -53 dBm for most cases, but begins at a desired signal of -58 dBm in the case at hand implies that the undesired signal is making up the difference—at total of about -54.7 dBm referred to the input* to get to the apparent AGC threshold of -53 dBm referred to the input. (This suggests that, had the desired signal level been much smaller, the threshold at which N+2 would engage the AGC would be 1.7 dB higher than that observed—*i.e.*, at U = -36.5 dBm + 1.7 dB = -34.8 dBm). Since the undesired input level on channel N+2 at the point of RF AGC action occurred at an input level of -36.5 dBm, it appears that the total power in the N+2 channel is attenuated by filtering by about 18.2 dB (*i.e.*, -36.5 dBm - [-54.7 dBm]) relative to the desired channel.

* This value was obtained by converting -53 dBm and -58 dBm to milliwatts, subtracting the two, and then converting back to dBm.

We examine the N+2 curve (Figure 11-2) to see whether it exhibits evidence of RF AGC action beginning at an undesired signal level in the region of -34.8 to -36.5 dBm. There are no obvious AGC bends in the curve; however, the undesired signal level for points on the curve ranges from -34.1 to -11.7 dBm. Thus it is likely that the AGC reductions of RF gain began just prior to the left-most point on the N+2 curve and continued throughout the curve.

*Deviation From Straight Line Near Receiver Threshold*

The portion of each of the three D/U curves (N+2/N+4, N+3/N+6, and N+4/N+8 in Figure 11-5) to the left of the AGC bend exhibits a primarily straight-line appearance with a slope consistent with a third-order interference process; however, there is an upward deviation from the straight line at the left end of each curve. Chapter 8 predicted that such deviations will occur as the desired signal level approaches $D_{MIN}$ for the receiver. Specifically, Table 11-2 predicts that, for a third-order interference process, the undesired signal at threshold will deviate from a straight-line projection by 1.0 dB when $D = D_{MIN} + 3$ dB and by 2.3 dB when $D = D_{MIN} + 1$ dB.

By using these predicted deviations together with the theoretical slope for a third-order process (Table 11-1) and a single measurement at D = -68 dBm (15 dB above $D_{MIN}$), one can predict the actual measured threshold values of undesired signal at $D_{MIN} + 3$ dB and $D_{MIN} + 1$ dB with errors not exceeding 0.6 dB for the former prediction and 1.2 dB for the latter in this particular case.

## N+1/N+2

Following the trend that was observed in the sub-section titled, "N+2/N+4, N+3/N+6, and N+4/N+8", one might expect that the curve for N+1/N+2 would look just like those for the other three paired signals except that it would be positioned above those curves on the D/U chart (Figure 11-5)—indicating that the TV is more susceptible to interference from the adjacent-channel pair than from the pairs that are further away from the desired channel. The measurements dash this expectation. Not only is the N+1/N+2 curve below the other three for most of its trajectory, but its shape is completely different—flat where the others are sloped and sloped where the others are essentially flat.

Also unexpected is that the N+1 curve overlays the N+1/N+2 curve for desired signals ranging from -73 dBm to -68 dBm. Apparently in this region, adding an undesired signal at N+2 to an existing one at N+1 causes no additional interference effect. Clearly, in this region, the IM3 contribution from the pair is negligible compared to the interference effect of N+1 alone, and the overall interference effect is *less than* that of the other pairs.

We can take a clue as to the reason for the unexpected behavior from the observations about AGC in the previous section. We note that a signal level exceeding -34.8 dBm on channel N+2 is able to cause the AGC to reduce the RF amplifier. (The observed threshold of -36.5 dBm was slightly less because the desired signal was also contributing to the energy seen by the AGC sampling point.) Given that RF AGC operation begins at a level of -53 dBm on channel N, at -34.8 dBm on channel N+2, and a higher, but unknown level on channels N+3 and beyond, we would expect that an undesired signal on channel N+1 would activate the RF AGC at a level somewhere between the channel N and channel N+1 values—*i.e.*, between -53 and -34.8 dBm. Furthermore, a typical bandpass filter at channel N would take a much bigger bite out of a signal at N+2 than out of a signal at N+1, so we might expect the AGC threshold for N+1 to be closer to that at N than to that at N+2. This suggests that the AGC threshold for N+2 is somewhere between that for N and the midpoint between those for N and N+2; hence, we would expect a threshold between -44 and -53 dBm. Looking at the U versus D plot in Figure 11-2, we see that only the left-most point on the N+1/N+2 curve has a U value within this range; all other points are above the range—suggesting that the RF AGC is active throughout the plotted curve, with the possible exception of the left-most point.

RF AGC operation throughout the curve provides a reason for the different behavior of N+1/N+2 interference relative to the other pairs. At all measured threshold points for N+1/N+2 (except possibly $D_{MIN}$ + 1 dB) the RF gain is reduced, reducing the IM3 at the mixer—apparently to a level below the N+1 interference mechanism that is at work.

The N+1/N+2 D/U ratio matches that for N+1 virtually exactly for desired signal levels of -73 to -68 dBm or so. Outside of this range, the paired signal shows more interference effect than N+1 alone. Since N+2 has a relatively low D/U ratio, the fact that interference susceptibility for the pair significantly exceeds that of N+1 indicates that the IM3 of the pair becomes significant outside of this narrow range. Why?

### *Desired Signal Levels Above -58 dBm*

At desired signal levels above -58 dBm, both the N+1/N+2 and N+1 plots of D/U (Figure 11-5) become upward sloped. In this region it is assumed that the interference mechanism for both single adjacent-channel case (N+1) and the paired signal case (N+1/N+2) is IM3. (Recall that IM3 creates shoulders around a single undesired signal that spill into the adjacent channel. Thus, for the first-adjacent-channel case, a pair of signals is not needed to create IM3 in the desired channel.) The slope of log-D versus log-U (Figure 11-3) goes to about three—consistent with IM3. The D/U of N+1/N+2 exceeds that of N+1 alone by about 3 dB—consistent with the expectation that more IM3 will be generated in the paired-signal case than in the single-signal case.

The fact that more IM3 occurs with N+1/N+2 than with N+1 in the right-hand part of the curves suggests that the interference is being generated by a nonlinearity occurring before the IF filter; so, again, it appears that the relevant nonlinearity is likely to be at the mixer or an earlier point in the tuner. The upturn of the D/U curves at a desired signal level around -63 dBm indicates that either the interference is being generated by a nonlinearity at an RF amplifier stage that is not controlled by the AGC or the interference is being generated by nonlinearity at the mixer *and* the AGC range for the RF amplifier has run out—*i.e.*, the RF amplifier is at its minimum gain. As a result, the D/U ratio rises with further increases in signal level. In Figure 11-5 the beginnings of a similar trend can be seen at the right-hand end of the curve for N+2/N+4, where D/U begins rising, but does so at a level *below* the D/U of N+1/N+2, indicating that N+2/N+4 generates less IM3 than does N+1/N+2 due to rolloff of the tracking filter in the RF stage.

### *Desired Signal Levels Below -73 dBm*

The upturn of D/U for N+1/N+2 relative to N+1 below -73 dBm was unexpected. Measurements were repeated to confirm the behavior; the result was the same.

In general all of the D/U curves exhibit an upturn from their straight-line projections as one moves leftward on the plot—toward $D_{MIN}$. Such an upturn is predicted in Chapter 8 (Table 8-2). The increase in D/U for N+1/N+2 above that of N+1, while D/U for N+2 remains low, suggests that IM3 for the signal pair becomes dominant again at low signal levels near the receiver's threshold. In fact, by the time desired signal drops to -82 dBm, D/U at N+1/N+2 has returned to its "rightful place" above the D/U for the other signal pairs. Thus, the adjacent undesired signal pair (N+1/N+2) finally exhibits a greater interference effect than that of the more distant signal pairs, an expectation which was foiled by AGC gain reductions in the RF stage at most other points along the curve. Apparently, the AGC-induced RF-gain reductions are gone or nearly gone by this point on the graph.

## SINGLE UNDESIRED SIGNALS

To facilitate the discussions below, Figure 11-6 and 11-7 were created to show the D/U ratio and threshold U, respectively, for single undesired signals (excluding the paired signal data that are included in Figures 11-1 and 11-2). For the most part the plots exhibit a near-straight-line character (in the log-log plots due to units of dB) in a region from about D = -78 dBm to D = -58 or -53 dBm.

To the left of this region, all D/U curves exhibit upturns from their straight line projections. Those upturns are attributed to the effect of receiver noise as the minimum signal threshold for the DTV receiver is approached.

Moving to the right, five of the plots (like three of the paired-signal plots) exhibit an abrupt downward bend in D/U to a relatively constant D/U ratio beginning at what we have termed the "AGC bend" at D = -53 dBm. The bend is caused by a stabilization of nonlinear interference mechanisms by AGC operation.

## N+1

The case of N+1 interference is discussed extensively in the previous section. The observed behavior differs among three regions of the curve.

In the middle section, from D = -78 dBm to D = -58 dBm, the D/U is constant, as would be expected for a linear interference process. However, we showed, in the "N+1/N+2" section of this chapter, that the AGC is actively adjusting RF gain throughout this section, so the constant D/U could be due to a linear interference mechanism or a non-linear one whose effect has been stabilized by the AGC. The "N+1/N+2" section also argued that the interference in this region occurs at a point beyond the first IF filter stage. It could be due to a nonlinearity in an IF amplifier stage or due to a linear process, such as inadequate IF selectivity allowing the edge of the N+1 signal to leak into the demodulator.

In the right-hand section, beyond D = -53 dBm, interference was shown to be the likely result of IM3 in the mixer after the AGC has reached the limit of its ability to reduce gain of the RF amplifier.

In the left-hand section, to the left of D = -73 dBm, there is a rise in the left-most two points on the curve that is attributable to the influence of receiver noise as the receiver threshold is approached. The fact that the rise is somewhat smaller than expected, coupled with a possible slight dip in D/U to the left of D = -73 dBm may suggest a diminishment of the interference mechanism that was dominant in the middle section of the curve. Such a diminishment could occur if that interference mechanism were nonlinear and if the AGC action ends as one moves leftward on the curve through that region. An alternative hypothesis is that the AGC-induced gain reductions might have increased the noise figure of the tuner and that the additional noise diminishes as one moves to the left on the curve and the AGC causes the RF gain to increase. (Cowley and Hanrahan state that noise figure "increases at 1 dB per dB of gain backoff...with some AGC architectures."[*])

## N+2

The D/U ratio for N+2 is shown in the bottom-most horizontal curve in Figure 11-6.

In the "N+2/N+4" section of this chapter, we showed that the AGC begins to reduce RF gain when the undesired signal level on N+2 exceeds a threshold of -34.8 dBm (or lower if the desired signal level approaches -53 dBm). Figure 11-7 shows that the undesired signal level throughout the N+2 curve exceeds this AGC threshold; thus, it appears that the AGC was controlling the RF gain throughout this curve.

The constant D/U ratio versus D throughout most of the plot is consistent with either a linear interference mechanism or an AGC-stabilized nonlinear one. The upturn at the left of the D/U plot (Figure 11-6) as D approaches $D_{MIN}$ is caused by the effect of receiver noise.

## N+3

The D/U curve for N+3 exhibits a steeper slope than the IM3-driven curves (Figure 1-1). On the plot of threshold U versus D, one can see that, for desired signal levels between -73 dBm and -53 dBm, the

[*] Cowley and Hanrahan, 2006.

threshold U is almost constant—increasing only by only 1.1 dB in a span of 20 dB change in desired signal level. A constant value of U would be expected for interference caused by a cross-modulation mechanism. The slope of log-U versus log-D for such a mechanism would be nominally zero, a value approached in this case, as can be seen in Figure 11-4.

*We suspect cross modulation in the mixer (a likely candidate for N+2 interference as well).* We attribute the abrupt bend in U (downward bend in D/U) toward a more constant D/U ratio at D = -53 dBm to AGC gain reductions in the RF amplifier driven by the desired signal level.

## N+4

For desired signal levels below D = -63 dBm, the log-D versus log-U curve for N+4 approaches 3—consistent with third-order interference mechanism (Figure 11-3). We are unable to propose such a mechanism in this case. The so-called the "half IF" taboo channel for analog TV was based on the second harmonic of an undesired signal beating with the second harmonic of the local oscillator frequency. Such an effect would create a susceptibility to interference that is centered 22 MHz (3 $^2/_3$ channels) above the desired channel—placing it predominantly at N+4. However, we anticipate that such an effect would be second-order in terms of the undesired signal level, and thus would exhibit a log-D versus log-U slope of two.

Between D = -63 dBm and D = -53 dBm, the slope increases significantly—possibly indicating a shift toward cross-modulation as the dominant interference mechanism.

As with many of the other curves, the D/U for N+4 flattens when D exceeds -53 dBm, due to AGC action in the RF amplifier.

## N+5

The slope of the N+5 curve to the left of the AGC bend at D = -53 dBm appears to be consistent with a third-order process. We are unable to propose a likely mechanism.

## N+6

Oddly, the *slope* of log-D versus log-U for N+6 appears to linearly increase with desired signal level until the AGC bend point, as can be seen in Figure 11-3. Mathematically, this would suggest that log-D is linearly related to U. Indeed, when desired signal level in dB is plotted against the threshold undesired signal level in linear power units (Figure 11-8), the result is strikingly linear to the left of the AGC bend. Whether there is a physical reason for this behavior or it is just a fluke is not known; however, we note that N+6 is one of the smaller interference vulnerabilities for this receiver, so no additional assessment has been performed.

## N+7

As was noted in Chapter 5 of this report, most of the DTV receivers tested for this program exhibited an increased susceptibility to interference at N+7 relative to the surrounding channels. The interference threshold at N+7 was found to be nearly constant in terms of undesired signal level as desired signal level was varied over a wide range up to -53 dBm. (See for example even numbered Figures 5-12 through 5-16.) The behavior can be seen here in Figure 11-7.

Initially, we attributed the interference phenomenon to the "IF beat" mechanism, which was one reason for the N+7 analog taboo.* "IF beat" interference is caused by an undesired signal on channel N+7 or N-7 beating with the desired signal—creating interference that can pass through the IF filter of the receiver. The lack of a corresponding susceptibility at N-7 (based on tests presented in Chapter 5) suggests that another mechanism may be at work. Furthermore, tests with a narrower-bandwidth interferer, presented

* The other reason was the potential for direct radiation of one TV's local oscillator to cause interference to another nearby receiver tuned seven channels higher.

in Chapter 7, suggest that the interference occurs only when the undesired signal spectrum overlaps the local oscillator frequency of the receiver. (Located 44 MHz above the center of the desired channel, the local oscillator falls within channel N+7.) This suggests some sort of direct interaction between the undesired signal and the local oscillator, although we have not identified a specific mechanism.

### N+14 and N+15

The mixer image band for a single-conversion TV tuner with a 44 MHz IF overlaps parts of channels N+14 and N+15. In Figure 11-6, the D/U ratio on these channels is seen to be essentially constant except when D approaches $D_{MIN}$. This is consistent with the fact that the mixer image interference mechanism is linear.

## SUMMARY

The detailed assessment of one receiver's out-of-channel interference rejection performance provides a basis for understanding the less detailed measurements for the other receivers. In particular, we note the following.

- Paired-signal IM3 can be one of the more dominant interference mechanisms, even at low signal levels.
- The expected increase in D/U ratio with increasing signal levels for nonlinear interference mechanisms is flattened above levels at which the AGC engages to stabilize the nonlinearity.
- AGC flattening of D/U ratios may begin at lower signal levels for close-in interference (*e.g.*, N+1) than for interferers spaced further from the desired channel. This can cause the unexpected result that, at some signal levels, a TV may be more tolerant of interference on the first-adjacent channels than on some other channels.
- As signal levels continue to increase, the flatting of D/U ratios by AGC may end, allowing D/U ratios to, again, increase with increasing signal levels.

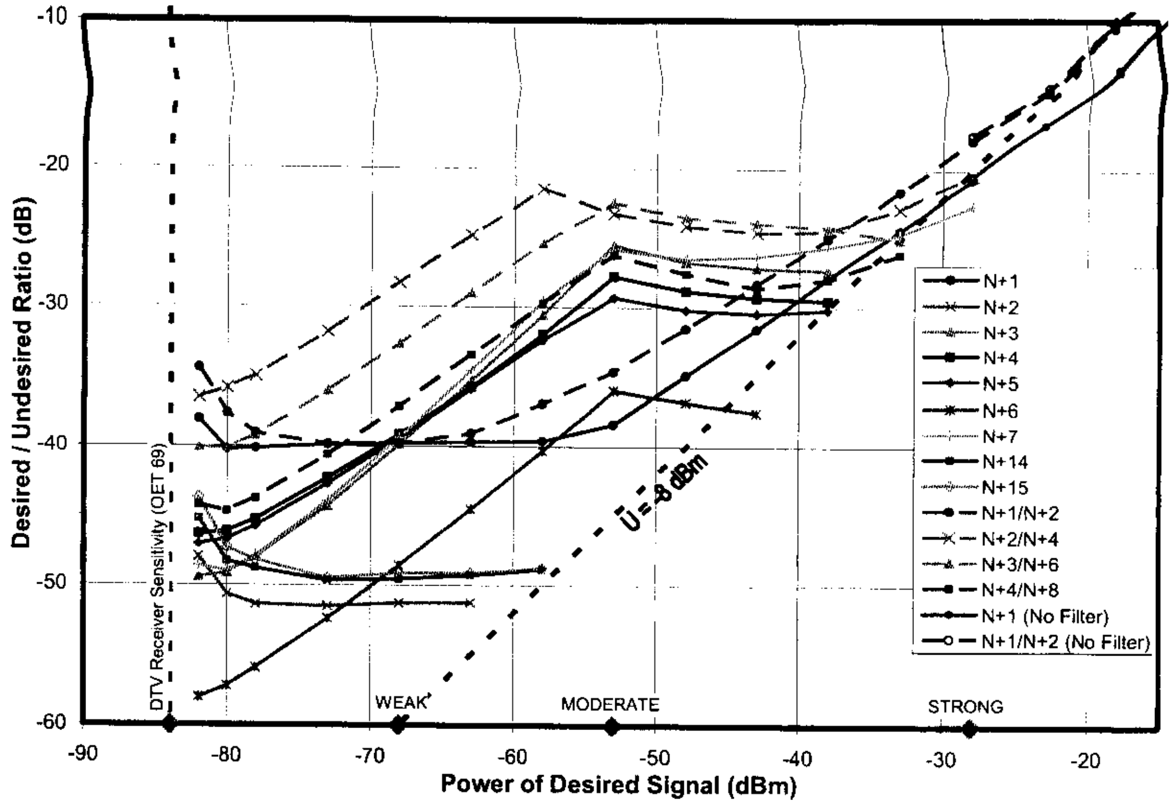


*Figure 11-1. D/U Versus D for Receiver D3 (Desired Signal on Channel 51)*

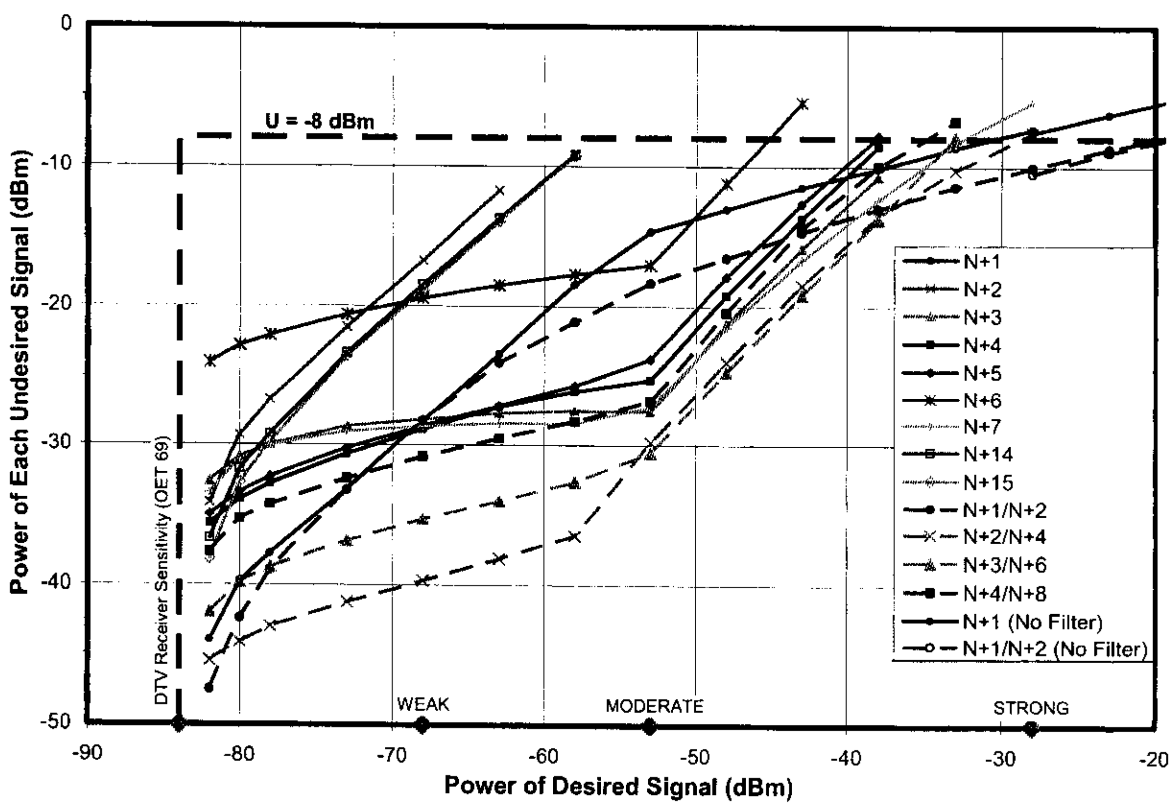


*Figure 11-2. Threshold U Versus D for Receiver D3 (Desired Signal on Channel 51)*

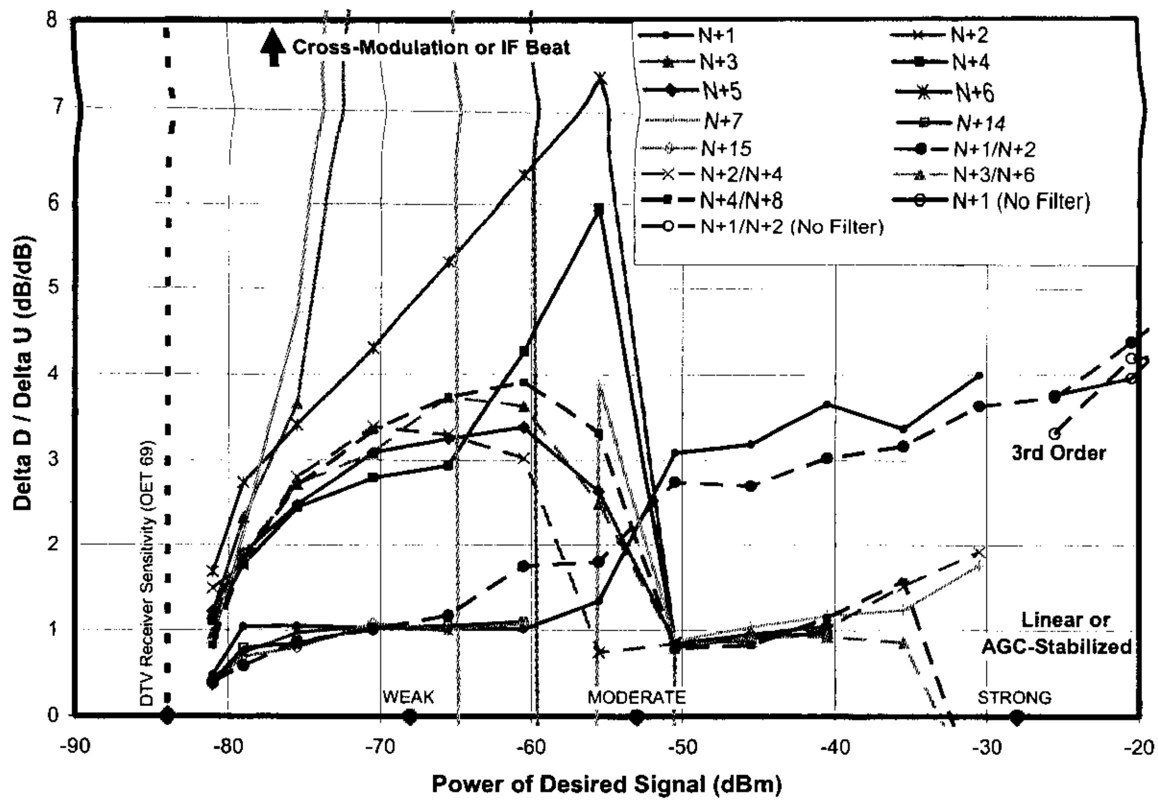


*Figure 11-3. Slope of Log-D versus Log-U for Receiver D3 (Desired Signal on Channel 51)*

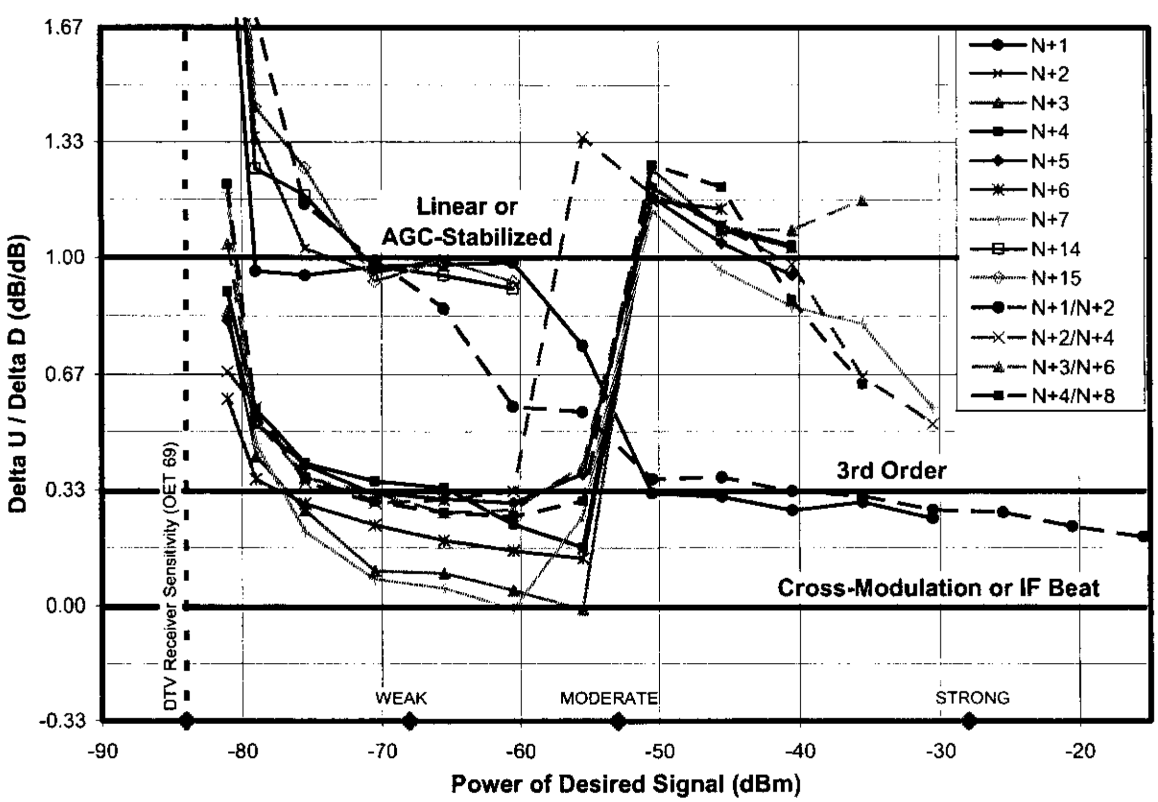


*Figure 11-4. Slope of Log-U versus Log-D for Receiver D3 (Desired Signal on Channel 51)*

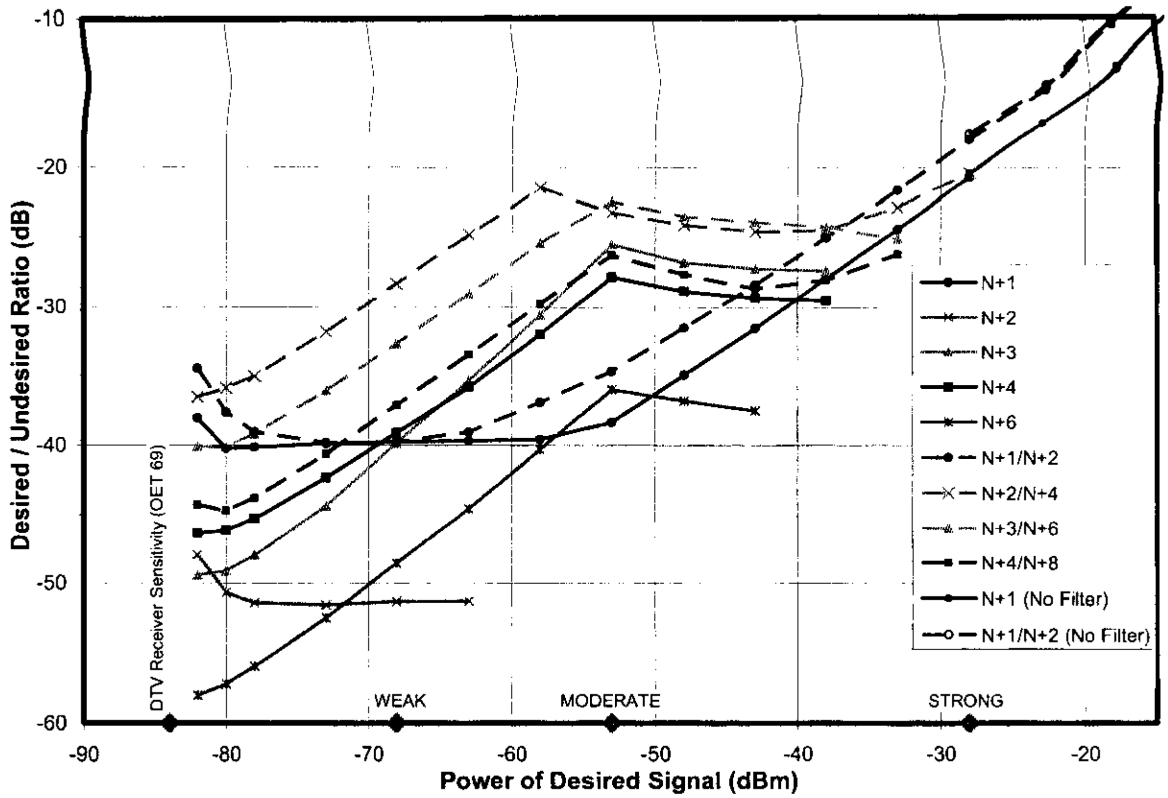


*Figure 11-5. D/U Versus D for Receiver D3—Paired Signals And Their Constituents*

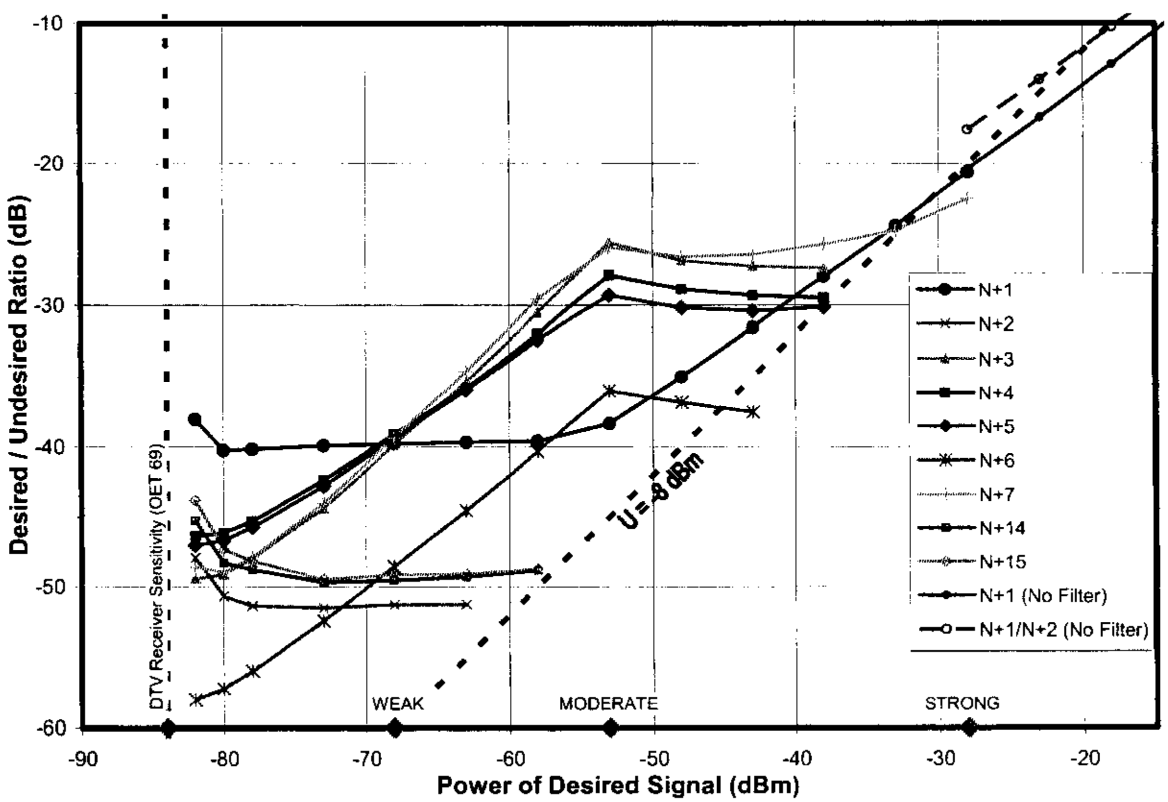


*Figure 11-6. D/U Versus D for Receiver D3—Single Undesired Signals*

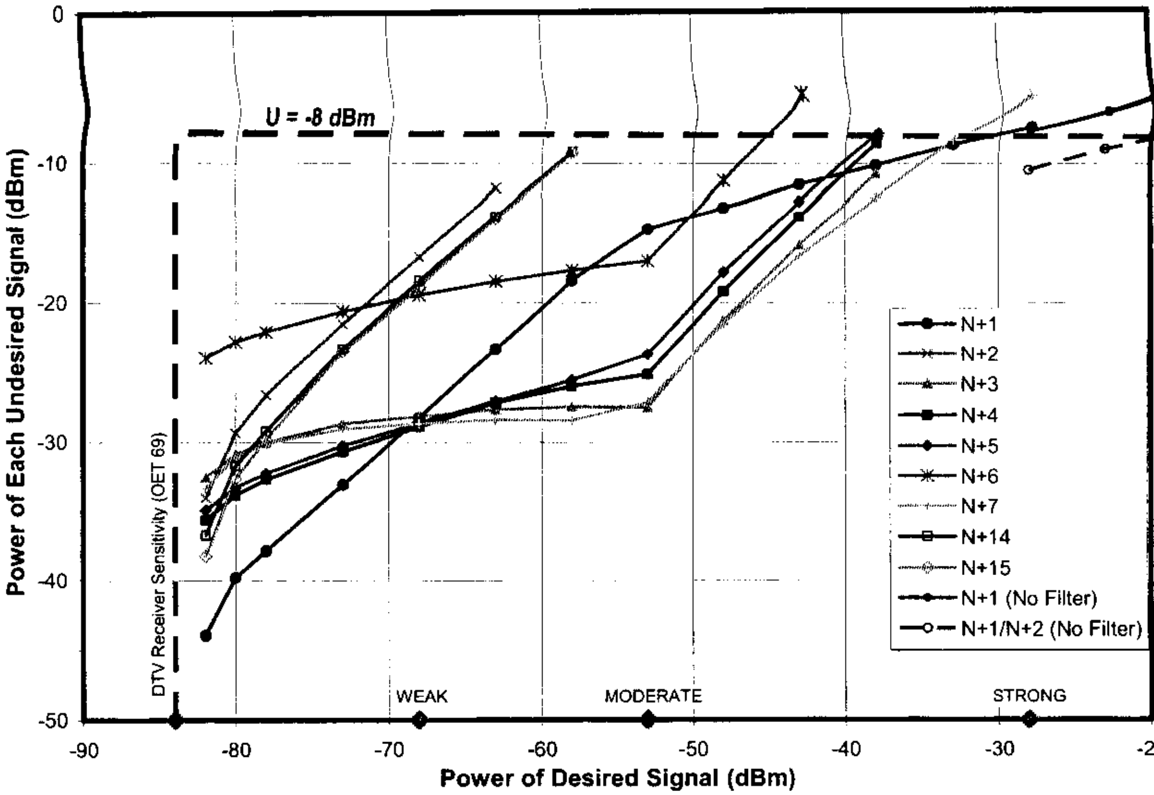


*Figure 11-7. Threshold U Versus D for Receiver D3—Single Undesired Signals*

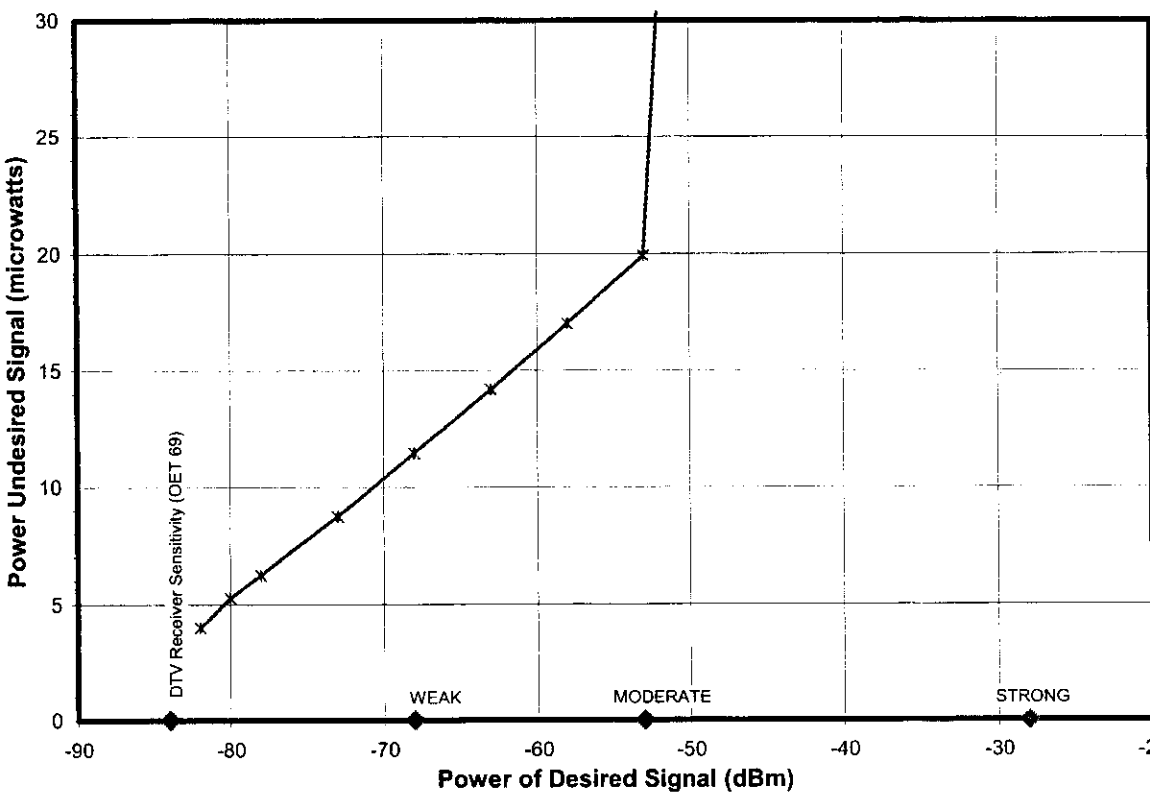


*Figure 11-8. Linear Undesired Power Versus Log-Desired Signal Power for N+6*

# CHAPTER 12
# EXTENDING THE RESULTS TO LOWER SIGNAL LEVELS

This chapter extrapolates the channel-30, single-channel interference rejection measurements from Chapter 5 of this report to a lower desired signal level, $D_{MIN}$ + 1 dB. It also employs measured data from Chapter 11 to evaluate the extrapolation method. The motivation for the extrapolation was explained in Chapter 2.

## *ORDER OF INTERFERENCE PROCESSES AND EFFECT OF AGC*

Chapter 8 presented a theoretical framework for understanding DTV interference susceptibilities. Table 12-1 summarizes the effects of the order of an interference mechanism and the state of the tuner's AGC on plots of threshold undesired versus desired signal power at the input to a TV according to that framework.

*Table 12-1. Characteristics of Log-Log Plots of Undesired Versus Desired Signal Power At TOV*

| | **Characteristics of Log-Log Plot of U Versus D** | |
|---|---|---|
| **Tuner AGC State→** and **Input Condition↓** | **Fixed gain** (or AGC operating to adjust gain of a tuner stage *after* the relevant nonlinearity[1]) | **AGC operating to adjust gain of a tuner stage prior to relevant nonlinearity[1]** |
| **D >> $D_{MIN}$** | Straight line with slope determined by the order of the interference mechanism. Slope is unity for linear interference. | Straight line with unity slope—matching that of a linear interference mechanism |
| **D approaching $D_{MIN}$** | Deviation from straight-line determined by order of interference mechanism | Deviation from straight-line:<br>• matches linear process if AGC is driven by U;<br>• determined by order of interference mechanism if AGC is driven by D |

*[1] Relevant nonlinearity refers to the nonlinearity responsible for a given observed interference effect. Slopes are listed in Table 8-1 and deviations from straight line are listed in Table 8-2 of Chapter 8.*

### Behavior for Desired Signal Levels From -68 dBm to -53 dBm

Over the desired signal range from -68 dBm to -53 dBm, the desired signal power is far enough above $D_{MIN}$ that the model predicts essentially straight-line behavior for log-U versus log-D, assuming that the interference mechanisms and AGC state remain the same throughout the region.

Figure 12-1 shows the slopes of threshold U vs D in dB units over this signal range for each of the receivers and channel offsets for which threshold measurements were successful (*i.e.*, the rejection performance was not beyond the measurement limit imposed by the test setup) at N = channel 30. The graph also includes horizontal reference lines corresponding to the slopes for the various interference mechanisms discussed in this report.

We note that some points clearly fit the expectations for a category of interference. For example, most of the receivers exhibit linear-like interference behavior when the undesired signal is on channels N-4 through N+2. It is considered likely that the actual interference mechanisms in those cases are nonlinear and that the linear-like behavior is caused by AGC operation. Interference to receiver D3 from undesired signals on channels N-15 through N-4 clearly fits the pattern of cross-modulation—a fact that was also discussed in Chapter 5 in the section entitled, "Taboo Effects and Other Observations", based on other evidence. The susceptibility of most receivers at N+7 also matches the slope expected for cross-modulation, although we suspect that the actual mechanism is different from those that have been postulated here based on the discussion in Chapter 7.

Some of the points fall in-between categories, possibly as a result of changes in the dominant interference mechanisms over the 15 dB range of desired signal amplitudes, or due to changes in AGC operation over that range.

## Behavior for Desired Signal Levels From $D_{MIN}$ + 3 dB to -68 dBm

As the desired signal drops to a point 3-dB above $D_{MIN}$, the deviation from straight-line behavior is expected to become significant—ranging from 1 to 3 dB (Table 8-2 of Chapter 8).

Because of this deviation, we have chosen to estimate the slope of the straight-line portion of the log-undesired versus log-desired signal curves in the region between $D_{MIN}$ + 3 dB and -68 dBm by what we will call the ***adjusted slope***. The slope will be estimated by first shifting the left-hand point of the range ($D = D_{MIN}$ + 3 dB) by 3 dB to the left (to $D = D_{MIN}$). Figures 8-1 through 8-4 (Chapter 8) showed that, in cases that are not stabilized by AGC operation, such a shift returns that point to the straight-line whose slope we are trying to predict, in all cases except the cross-modulation case. With AGC operation driven by the undesired signal level, the same will be true. Slope estimated in this way will deviate from that of the straight-line portion we would like to estimate in cases involving cross-modulation or involving AGC operation driven by the desired signal level. Neglecting these cases, the expected slopes of log-U versus log-D for linear (or AGC-stabilized nonlinear), second order, and third order interference processes are 1, 1/2, and 1/3 dB/dB, respectively, and the expected slopes of log-D versus log-U are 1, 2, and 3 dB/dB.

For the cross-modulation case, Figure 8-4 showed that the straight-line projection should have a slope of zero for log-U versus log-D or an infinite slope for log-D versus log-U. The shift of the left hand point of the range by 3 dB (for a log-U versus log-D plot) does not return that point to the straight line in this case. Rather, in the nominal case, where $D_{MIN}$ = -84 dBm, we are measuring the slope of a line connecting the points (D = -68 dBm, $U = U_T$) and (D = -84 dBm, $U = U_T$ - 1.5 dB), where $U_T$ is the constant threshold value of U along the straight line. The expected slope, then, is 0.09 for log-U versus log-D or 10.7 for log-D versus log-U, though small measurement errors could cause the latter number to vary widely.

Similarly, for the case of nonlinear interference stabilized by AGC operation driven by desired signal level, the adjusted slope of log-U versus log-D will be somewhat less than the unity slope of the straight-line portion of the curve, and the slope of the log-D versus log-U curve will exceed unity.

Figure 12-2 shows the "adjusted slope" of log-log curves of U versus D computed by the above method for D from $D_{MIN}$ + 3 dB to -68 dBm. Figure 12-3 shows the adjusted slope of log-log curves of D versus U—the reciprocal of the slopes shown in Figure 12-2. For reasons discussed above, the slopes of the cross-modulation case generally fall above zero on the first plot and below infinity for the second. Similarly, some of the AGC-stabilized cases fall below unity slope of the first plot and above unity on the second.

# *EXTRAPOLATION TO $D = D_{MIN}$ + 1 DB*

The extrapolations to $D = D_{MIN}$ + 1 dB will be based on measurements at $D = D_{MIN}$ + 3 dB—an extrapolation distance (in terms of desired signal level) of only 2 dB. Though the extrapolation distance is short, it should be recognized that threshold undesired signal levels are expected to change rapidly as